3.4 RISK CHARACTERIZATION

Risk characterization is the summarizing step of a risk assessment, which integrates the hazard and exposure assessment components and presents overall conclusions. Risk characterization typically includes a description of the assumptions, scientific judgments, and uncertainties that are part of this process. There are several types of risk assessment ranging from screening level to comprehensive, and differing according to framework: site-specific, single chemical, or multiple chemical. This risk assessment is best described as a screening level assessment of multiple chemicals identified as belonging to a particular use cluster (MHC) in the PWB industry. This is a screening level, rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. The intended audience of this risk characterization is the PWB industry and others with a stake in the practices of this industry.

The focus of this risk characterization is on chronic (long-term) exposure to chemicals that may cause cancer or other toxic effects rather than on acute toxicity from brief exposures to chemicals. The focus is also on those health effects from chronic exposures that could be used to measure risk. In addition, this risk characterization does not consider chemical persistence. The Process Safety Assessment (Section 3.5) includes further information on chemical safety concerns.

The goals of the PWB project risk characterization are:

- To present conclusions and uncertainties associated with a screening level health risk assessment of chemicals used in the MHC process of PWB manufacture.
- To integrate chemical hazard and exposure information to assess risks from ambient environment and occupational exposures from the MHC process.
- To use reasonable and consistent assumptions across alternatives, so health risks associated with one alternative can be compared to the health risks associated with other alternatives.
- To identify the areas of concern that differ among the substitutes in a manner that facilitates decision-making.

This section contains a summary of the exposure assessment (Section 3.4.1), the human health hazards assessment (Section 3.4.2), a description of methods used to calculate risk indicators (Section 3.4.3), results (Section 3.4.4), discussion of uncertainties (Section 3.4.5), and conclusions (Section 3.4.6). Detailed exposure data are presented separately in the Exposure Assessment (Section 3.2) and in Appendix E.

3.4.1 Summary of Exposure Assessment

The exposure assessment uses a “model facility” approach, where as much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including PWB shops in the U.S. and abroad, supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any

one facility, and actual exposure (and risk) could vary substantially, depending on site-specific operating conditions and other factors.

Chemical exposures to PWB workers and the general population were estimated by combining information gathered from industry (IPC Workplace Practices Questionnaire and Performance Demonstration data, MSDSs, and other available information) with standard EPA exposure assumptions (e.g., for inhalation rate, surface area of dermal contact, and other parameters). The pathways identified for potential exposure from MHC process baths were inhalation and dermal contact for workers, and inhalation contact only for the general populace living near a PWB facility.

The possible impacts from chemical spills are not addressed due to the pre-defined scope of this assessment. In addition, environmental releases to surface water were not quantified because chemical constituents and concentrations in wastewater could not be adequately characterized for the MHC line alone. This is because PWB manufacturers typically combine wastewater effluent from the MHC process line with effluent from other PWB manufacturing processes prior to on-site wastewater pretreatment. The pretreated wastewater is then discharged to a POTW. Many PWB manufacturers measure copper concentrations in effluent from on-site pretreatment facilities in accordance with POTW discharge permits, but they do not measure copper concentrations in MHC line effluent prior to pretreatment. Because there are many sources of copper-contaminated wastewater in PWB manufacturing, the contribution of the MHC line to overall copper discharges could not be estimated. Furthermore, most of the MHC alternatives contain copper, but because these technologies are only now being implemented in the U.S., their influence on total copper discharges from a PWB facility cannot be determined. Finally, while data are available on copper discharges from PWB facilities, data are not available for some of the other metals found in alternatives to electroless copper. Although ecological hazards are assessed in Section 3.3, without exposure or release data a comparative evaluation of ecological (aquatic) risk could not be performed.

Inhalation exposure could occur by breathing air containing vapor or aerosol-phase chemicals from the MHC process line. Inhalation exposures to workers from non-conveyorized lines are estimated in the exposure assessment. Inhalation exposure to workers from conveyorized MHC lines is assumed to be negligible because the lines are typically enclosed and vented to the outside. The model used to estimate daily inhalation exposure is from the EPA *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments* (EPA, 1991a):

$$I = (Cm)(b)(h)$$

where:

- I = daily inhalation potential dose rate (mg/day)
- Cm = airborne concentration of substance (mg/m^3)
- b = inhalation rate (m^3/hr)
- h = duration (hr/day)

Daily exposures are then averaged over a lifetime (70 years) for carcinogens, and over the exposure duration (e.g., 25 years working in a facility) for non-carcinogens,[11] using the following equations:

For carcinogens:

$$LADD = (I)(EF)(ED)/[(BW)(AT_{CAR})]$$

For non-carcinogens:

$$ADD = (I)(EF)(ED)/[(BW)(AT_{NC})]$$

where:

LADD	=	lifetime average daily dose (mg/kg-day)
ADD	=	average daily dose (mg/kg-day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	body weight (kg)
AT_{CAR}	=	averaging time for carcinogenic effects (days)
AT_{NC}	=	averaging time for non-carcinogenic chronic effects (days)

The daily intake for inhalation exposure to workers was calculated by first modeling chemical emissions from MHC baths with three air-transport mechanisms: liquid surface diffusion (desorption), bubble desorption, and aerosol generation and ejection. This chemical emission rate was combined with data from the IPC Workplace Practices Questionnaire and Performance Demonstration regarding process room size and air turnover rate to estimate an average indoor air concentration for the process area. An uncertainty and sensitivity analysis of the air transport models suggests that the air turnover (ventilation) rate assumption greatly influences the estimated air concentration in the process area because of its large variability (see the Exposure Assessment, Section 3.2.3).

Inhalation exposure to a hypothetical population located near a model PWB facility was estimated using the Industrial Source Complex - Long Term (ISCLT) air dispersion model. The modeled air concentrations of each contaminant were determined at 100 meters radially from a PWB facility, and the highest estimated air concentration was used. This model estimates air concentrations from the process bath emission rates for all processes. These emissions were assumed to be vented to the ambient environment at the rate emitted from the baths. Inhalation exposures estimated for the public living 100 meters away from a PWB facility were very low (approximately 10,000 times lower than occupational exposures).

[11] Different averaging times are used for characterizing risk for carcinogenic and non-carcinogenic effects. For carcinogenic agents, because even a single incidence of exposure is assumed to have the potential to cause cancer throughout an individual's lifetime, the length of exposure to that agent is averaged over a lifetime. An additional factor is that the cancer latency period may extend beyond the period of working years before it is discernible. For chemicals exhibiting non-cancer health effects from chronic (longer-term) exposure, where there is an exposure threshold (a level below which effects are not expected to occur), only the time period when exposure is occurring is assumed to be relevant and is used as the averaging time.

Dermal exposure could occur when skin comes in contact with the bath solution while dipping boards, adding bath replacement chemicals, etc. Although the data suggest that most MHC line operators do wear gloves, it was assumed in this evaluation that workers do not wear gloves to account for the fraction that do not. Otherwise, dermal exposure is expected to be negligible. For dermal exposures, the flux of a material through the skin was estimated based on EPA, 1992a:

$$D = (S)(C)(f)(h)(0.001)$$

where:

- D = dermal potential dose rate (mg/day)
- S = surface area of contact (cm^2)
- C = concentration of chemical in the bath (mg/L)
- f = flux through skin (cm/hour)
- h = duration (hours/day)

  with a conversion factor of 0.001 (L/cm^3)

It should be noted that the above equation was developed for exposures with an infinite volume of liquid or boundary layer contacting the skin, such as swimming or bathing. Occupational conditions of dermal contact are likely to be more finite in comparison, resulting in possible overestimates of flux through the skin.

As for inhalation, daily dermal exposures were then averaged over a lifetime for carcinogens, and over the exposure duration for non-carcinogens, using the following equations:

For carcinogens:

$$LADD = (D)(EF)(ED)/[(BW)(AT_{CAR})]$$

For non-carcinogens:

$$ADD = (D)(EF)(ED)/[(BW)(AT_{NC})]$$

For dermal exposure, the concentration of chemical in the bath and duration of contact for workers was obtained from publicly-available bath chemistry data, disclosed proprietary chemical information, and IPC Workplace Practices Questionnaire information, respectively. A permeability coefficient (rate of penetration through skin) was estimated for organics and a default rate assumption was used for inorganics. Reliance on such estimates in the absence of data is a source of uncertainty in the exposure assessment.

Key assumptions in the exposure assessment include the following:

- For dermal exposure, it was assumed that line operators do not wear gloves. Although the data suggests that most MHC line operators do wear gloves, it was assumed for this evaluation that workers do not wear gloves to account for the subset of workers who do not wear proper personal protective equipment.
- For dermal exposure, it was assumed that all non-conveyorized lines are manual hoist.

- The worker is assumed to have potential dermal contact for the entire time spent in the MHC area, divided equally among the baths. This does not mean that a worker has both hands immersed in a bath for that entire time; but that the skin is in contact with bath solution (i.e., the hands may remain wet from contact). This assumption may result in an overestimate of dermal exposure.
- For estimating ambient (outdoor) air concentrations, it was assumed that no air pollution control technologies are used to remove airborne chemicals from facility air prior to venting it to the outside.
- For inhalation exposure to workers, it was assumed that chemical emissions to air in the process room from conveyorized lines are negligible, and that no vapor control devices (e.g., bath covers) are used on baths in non-conveyorized lines.
- For air concentrations, the model assumes complete mixing in the process room and that concentrations do not change with time (steady state).
- For all exposures, it was assumed that there is one MHC process line and one line operator per shift in a process area.
- For characterizing the chemical constituents in the MHC process baths, it was assumed that the form (speciation) and concentration of all chemicals in the baths are constant over time, and that MSDSs accurately reflect the concentrations in product lines. If reported constituent weight percents on an MSDS total less than 100 percent, the remainder is assumed to be water. These assumptions are discussed further below.

The exposure assessment does not account for any side reactions occurring in the baths (e.g., the Cannizarro side reaction, which involves the reaction of formaldehyde in electroless copper baths). A study performed by Merix Corporation found that for every one mole of formaldehyde reacting in the intended copper deposition process, approximately one mole was reacting with hydroxide in a Cannizarro side reaction to produce formate ion and methanol (Williamson, 1996). Other studies have found that the Cannizarro reaction tendency increases with the alkalinity of the bath. The exposure assessment assumed that the formaldehyde in the bath is not reacted, and is available to be emitted as formaldehyde. This assumption could tend to overestimate formaldehyde exposures, and thus risk. However, if side reactions are occurring with other chemicals that result in the formation of other toxic chemicals (such as methanol), risk from these chemicals could be underestimated. A search for literature references to studies of side reactions occurring in PWB baths did not produce sufficient information to quantify the risk of reaction products in this risk characterization.

Chemical concentrations in baths are based on publicly-available chemistry data, including MSDSs, partial proprietary chemical information, and supplier Product Data Sheets that describe how to mix and maintain chemical baths. Many MSDSs provided concentration ranges for chemical constituents instead of absolute concentrations, in which case it was assumed that a chemical is present at the mid-point of the reported concentration range. This assumption may either overestimate or underestimate risk for chemicals, depending on their actual concentrations.

Using MSDS data for an exposure assessment can also lead to an underestimate of overall risk from using a process because the identities of many proprietary ingredients are not included

in the MSDSs. Efforts were made to obtain this information from suppliers of MHC bath formulations and proprietary information has been received from three of the seven suppliers.[12]

Assumptions and parameter values used in these equations and results of the exposure calculations are presented in the Exposure Assessment (Section 3.2). In order to provide information about the position an exposure estimate has in the distribution of possible outcomes, exposure (or risk) descriptors are used following EPA's (EPA, 1992b) *Guidelines for Exposure Assessment*. For this risk characterization, the exposure assessment uses whenever possible a combination of central tendency (either an average or median estimate) and high-end (90th percentile)[13] assumptions, as would be used for an overall high-end exposure estimate. The 90th percentile is used for:

- Hours per day of workplace exposure.
- Exposure frequency (days per year).
- Exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures).
- The time and frequency of chemical bath and filter replacements, conveyor equipment cleaning and chemical bath sampling (minutes per occurrence and number of occurrences per year).
- Estimated workplace air concentrations.

Average values are used for:

- Body weight.
- Concentration of chemical in bath.
- The number of baths in a given process.

Some values used in the exposure calculations, however, are better characterized as "what-if," especially pertaining to bath concentrations, use of gloves, and process area ventilation rates for the model facility. ("What-if" represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.) Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a "what-if" descriptor, the entire assessment should be considered "what-if."

[12] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. Atotech provided information on one proprietary ingredient. W.R. Grace was preparing to transfer information on proprietary chemical ingredients in the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information on their MHC technologies. The absence of information on proprietary chemical ingredients is a significant source of uncertainty in the risk characterization. Risk information for proprietary ingredients, as available, is presented in this CTSA, but chemical identities, concentrations, and chemical properties are not listed.

[13] For exposure data from the IPC Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

3.4.2 Summary of Human Health Hazards Assessment

Toxicity data in the form of RfDs, RfCs, NOAELs, LOAELs, and cancer slope (cancer potency) factors were compiled for inhalation and dermal pathways. CCs and aquatic toxicity hazard ranks for aquatic species were calculated from aquatic toxicity data on PWB chemicals, but ecological risk characterization was not carried out because the aquatic exposure could not be estimated.

Formaldehyde was the only non-proprietary chemical with an established cancer slope (cancer potency) factor. Other non-proprietary chemicals in the MHC processes are suspected carcinogens, but do not have established slope factors. Dimethylformamide and carbon black have been determined by IARC to possibly be carcinogenic to humans (IARC Group 2B). Dimethylformamide is used by at least one supplier in the electroless copper process. Carbon black is used in the carbon and conductive ink processes. Because slope factors (cancer potency values) are needed for quantitative estimates of cancer risk, cancer risk results are only presented for formaldehyde. Two proprietary chemicals used in the graphite and electroless copper processes, cyclic ether and alkyl oxide, have cancer slope factors. One proprietary chemical used in the electroless copper process, trisodium acetate amine B, was determined to possibly be carcinogenic to humans but does not have an established slope factor.

3.4.3 Methods Used to Calculate Human Health Risks

Estimates of human health risk from chemical exposure are characterized here in terms of excess lifetime cancer risk, hazard quotient (HQ), and margin of exposure (MOE). This section defines these risk indicators and discusses the methods for calculating each of them.

Cancer Risk

Cancer risks are expressed as the excess probability of an individual developing cancer over a lifetime from chemical exposure. For chemicals classified as carcinogens, an upper bound excess lifetime cancer risk, expressed as a unitless probability, was estimated by the following equation:

cancer risk = LADD x slope factor

where:

Cancer Risk = the excess probability of developing cancer over a lifetime as a result of exposure to a potential carcinogen. The estimated risks are the upper bound excess lifetime cancer risks for an individual. (*Upper bound* refers to the method of determining a slope factor, where the upper bound value for the slope of the dose-response curve is used. *Excess* means the estimated cancer risk is in addition to the already-existing background risk of an individual contracting cancer from all other causes.)

LADD = the lifetime average daily dose, the estimated potential daily dose rate received during the exposure duration, averaged over a 70-year lifetime (in mg/kg-day). LADDs were calculated in the Exposure Assessment (Section 3.2).

Slope factor (q_1 *) is defined in Section 3.3.1.

Non-Cancer Risk Indicators

Non-cancer risk estimates are expressed either as a HQ or as a MOE, depending on whether or not RfDs and RfCs are available. There is generally a higher level of confidence in the HQ than the MOE, especially if the HQ is based on an RfD or RfC that has been peer-reviewed by EPA. If an RfD or RfC is available, the HQ is calculated to estimate risk from chemicals that exhibit chronic, non-cancer toxicity. (RfDs and RfCs are defined in Section 3.3.2.) The HQ is the unitless ratio of the RfD (or RfC) to the potential dose rate. For MHC chemicals that exhibit non-cancer toxicity, the HQ was calculated by:

$$HQ = ADD/RfD$$

where:

ADD = average daily dose rate, the amount of a chemical ingested, inhaled, or applied to the skin per unit time, averaged over the exposure duration (in mg/kg-day). ADDs were calculated in the Exposure Assessment (Section 3.2).

The HQ is based on the assumption that there is a level of exposure (i.e., the RfD or RfC) below which it is unlikely, even for sensitive subgroups, to experience adverse health effects. Unlike cancer risk, the HQ does not express *probability* and is not necessarily linear; that is, an HQ of ten does not mean that adverse health effects are ten times more likely to occur than for an HQ of one. However, the ratio of estimated dose to RfD/RfC reflects level of concern.

For chemicals where an RfD or RfC was not available, a MOE was calculated by:

$$MOE = NOAEL/ADD \text{ or } LOAEL/ADD$$

As with the HQ, the MOE is not a probabilistic statement of risk. The ratio for calculating MOE is the inverse of the HQ, so that a high HQ (exceeding one) indicates a potential concern, whereas a high MOE (exceeding 100 for a NOAEL-based MOE or 1,000 for a LOAEL-based MOE) indicates a low concern level. (NOAELS and LOAELs are defined in Section 3.3.2.) As the MOE increases, the level of concern decreases. (As the HQ increases, the level of concern also increases.)

Both the exposure estimates and toxicity data are specific to the route of exposure (i.e., inhalation, oral, or dermal). Very few RfDs, NOAELs, or LOAELs were available for dermal exposure. If oral data were available, the following adjustments were made to calculate dermal values:

$$RfD_{DER} = (RfD_{ORAL})(\text{GI absorption})$$
$$NOAEL/LOAEL_{DER} = (NOAEL \text{ or } LOAEL_{ORAL})(\text{GI absorption})$$
$$SF_{DER} = (SF_{ORAL})/\text{GI absorption})$$

where:

RfD_{DER} = reference dose adjusted for dermal exposure (mg/kg-day)
$NOAEL/LOAEL_{DER}$ = NOAEL or LOAEL adjusted for dermal exposure (mg/kg-day)

SF_{DER} = cancer slope factor adjusted for dermal exposure $(mg/kg\text{-}day)^{-1}$
GI absorption = gastrointestinal absorption efficiency

This adjustment is made to account for the fact that the oral RfDs, NOAELs, and LOAELs are based on an applied dose, while dermal exposure represents an estimated absorbed dose. The oral RfDs, NOAELs, and LOAELs used to assess dermal risks were therefore adjusted using gastro-intestinal (GI) absorption to reflect an absorbed dose. Table 3.35 lists the GI absorption data used in calculating risk from dermal exposure.

Table 3.35 Absorption Percentages

Chemicals[a]	GI Tract Absorption (%)	Source of Data
1,3-Benzenediol	100	NTP, 1992
2-Ethoxyethanol	100	assumption[b]
Ammonium Chloride	97	Reynolds, 1982
Benzotriazole	20	assumption[b]
Boric Acid	90	EPA, 1990
Copper (I) Chloride	60	EPA, 1994a
Diethylene Glycol Ethyl Ether	20	assumption[b]
Diethylene Glycol Methyl Ether	20	assumption[b]
Diethylene Glycol n-Butyl Ether	20	assumption[b]
Dimethylformamide	20	assumption[b]
Ethanolamine	20	assumption[b]
Ethylene Glycol	100	ATSDR, 1993
Fluoroboric Acid	100	Stokinger, 1981
Formaldehyde	1	EPA, 1995b
Hydrogen Peroxide	5	default (EPA, 1989)
Hydroxyacetic Acid	20	assumption[b]
Isopropyl Alcohol, 2-Propanol	20	assumption[b]
Methanol	100	Lington & Bevan, 1994
Palladium	5	Beliles, 1994
Palladium Chloride	5	Beliles, 1994
Phenol	20	assumption[b]
Potassium Cyanide	5	default (EPA, 1989)
Silver	21	ATSDR, 1990b
Sodium Chlorite	5	default (EPA, 1989)
Sodium Cyanide	5	default (EPA, 1989)
Sodium Sulfate	100	HSDB, 1995
Stannous Chloride	3	ATSDR, 1992
Vanillin	6	Kirwin and Galvin, 1993

[a] Includes only those chemicals where dermal HQs or MOEs were calculated. Proprietary chemical data are not presented in order to protect proprietary chemical identities.
[b] An assumption of 20 percent was made for organic chemicals when no other data were available.

3.4.4 Results of Calculating Risk Indicators

This section presents the results of calculating risk indicators for both the occupational setting and the ambient (outdoor) environment. When considering these risk characterization results, it should be remembered that the results are intended for use in relative risk comparisons between processes based on a model PWB facility, and should not be used as absolute indicators for potential health risks to MHC line workers or to the public.

Occupational Setting

Estimated cancer risks and non-cancer risk indicators from occupational exposure to MHC chemicals are presented below. It should be noted that no epidemiological studies of health effects among PWB workers were located.

Inhalation Cancer Risk. The electroless copper and graphite processes are the only processes containing chemicals for which a cancer slope (cancer potency) factor is available. Formaldehyde, in the electroless copper process, is the only non-proprietary chemical for which an inhalation cancer risk has been estimated. Formaldehyde has an EPA weight-of-evidence classification of Group B1, a Probable Human Carcinogen. The EPA Group B1 classification is typically based on limited evidence of carcinogenicity in humans, sufficient evidence of carcinogenicity in animals, and additional supporting evidence. The cancer slope factor for formaldehyde is based exclusively on animal data, and is associated with nasal cancer.

Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. The exposure estimates use 90th percentile modeled air concentrations (0.62 mg/m^3 for formaldehyde in the non-conveyorized electroless copper process), which means that, based on the IPC Workplace Practices Questionnaire data and publicly-available information on bath concentrations, approximately 90 percent of the facilities are expected to have lower air concentrations and, therefore, lower risks. Using 90th percentile data is consistent with EPA policy for estimating upper-bound exposures.

With regard to formaldehyde cancer risk, EPA in 1987 issued a risk assessment in which formaldehyde was classified as a Group B1 Probable Human Carcinogen; in addition it was determined to be an irritant to the eyes and respiratory tract. A quantitative risk assessment for cancer was presented using available exposure data and a cancer slope (cancer potency) factor of 0.046 per milligram formaldehyde per kilogram body weight per day. In 1991, EPA proposed a modification of this assessment using additional animal testing and exposure data that had become available. Incorporation of this new data would result in an estimated cancer slope factor of 0.00094 per milligram formaldehyde per kilogram body weight per day, a 50-fold reduction from the current cancer slope factor. However, EPA's Science Advisory Board recommended that formaldehyde cancer risk be presented as a range of risk estimates using data from both the 1987 and 1991 assessments, due to the many uncertainties and data gaps that preclude the use of one assessment to the exclusion of the other. Therefore, upper bound maximum individual cancer risk over a lifetime is presented as a range from 1×10^{-3} (one in 1,000) to 2×10^{-5} (two in 100,000 or one in 50,000) based on a workplace concentration of 0.62 milligrams formaldehyde

per cubic meter of air (over an 8 hour-day) for line operators using the non-conveyorized electroless copper process. It should be pointed out that intensity of exposures to formaldehyde (air concentration) may be more important than average exposure levels over an 8-hour day in increasing cancer risk (Hernandez et al., 1994). The use of modeled, steady state, workplace air concentrations instead of actual monitoring data of average and peak concentrations thus emerges as a significant source of uncertainty in estimating cancer risk to workers exposed to formaldehyde in this industry. The available toxicological data do not indicate that dermal exposure to formaldehyde increases cancer risk, but no dermal cancer studies were located.

To provide further information on the possible variation in occupational formaldehyde exposure and risk estimates, formaldehyde cancer risk is also estimated using average and median values, as would be done for a central tendency exposure estimate.[14] The following median or average parameter values are used:

- The 50th percentile air concentration estimated from the quantitative uncertainty analysis (Section 3.2.3) of 0.055 mg/m^3 (compared to the high-end point estimate of 0.62 mg/m^3).
- The median job tenure for men in the U.S. of 4.0 years (Bureau of Labor Statistics, 1997) (compared to the 95th percentile of 25 years).
- The average value of 6.8 hrs/day for a line operator from the IPC Workplace Practices Questionnaire (compared to the 90th percentile of 8 hrs/day).
- The average exposure frequency of 250 days/year from the IPC Workplace Practices Questionnaire (compared to the 90th percentile of 306 days/year).

Using these values, there is approximately a 100-fold reduction in estimated exposure with the estimated "central tendency" LADD of 2.6×10^{-4} mg/kg-day. Combined with the slope factor of 0.046 per mg/kg-day, this results in a cancer risk of 1×10^{-5} (one in 100,000). Considering the 50-fold reduction in cancer potency (with a slope factor of 0.00092 per mg/kg-day) the cancer risk would be 2×10^{-9} (one in five million).

Inhalation cancer risk was also estimated for one proprietary chemical, alkyl oxide, in the non-conveyorized electroless copper process. This is discussed to a limited extent, however, to protect proprietary ingredient identity. The line operator inhalation exposure estimate for alkyl oxide[15] results in an estimated upper bound excess individual lifetime cancer risk of 3×10^{-7} based on high end exposure.

[14] This "central tendency" estimate should also be considered a "what-if" exposure estimate, because of the uncertainty of the process area ventilation rate data.

[15] It should be noted that alkyl oxide is present in the electroless copper and graphite baths at trace concentrations (less than one part per million) and it has a relatively high tendency to evaporate. Based on air modeling estimates, and assuming 100 liter baths, all of this chemical would be released to air within one hour. The assumption that chemical concentration in the baths remains constant over time would result, in this case, in large over-estimates of inhalation exposure. A correction factor was applied to the calculated cancer risks to reflect exposure from the chemical being present for one hour in the baths, at a yearly frequency equal to the bath replacement frequency.

Risks to other workers were assumed to be proportional to the amount of time spent in the process area. Based on the IPC Workplace Practices Questionnaire data, the average line operator spends 1,900 hours per year in the MHC process area. Annual average exposure times (i.e., time spent in the process area) for various worker types from the workplace practices database are listed below. The number in parenthesis is the ratio of average time for that worker type to the average time for a line operator.

- Contract worker: 62 hours per year (0.033).
- Laboratory technician: 1,100 hours per year (0.58).
- Maintenance worker: 930 hours per year (0.49).
- Supervisor: 1,150 hours per year (0.61).
- Wastewater treatment operator: 1,140 hours per year (0.60).
- Other: 1,030 hours per year (0.54).

Dermal Cancer Risk. Dermal cancer risks were estimated for two proprietary chemicals, alkyl oxide and cyclic ether, in the graphite and electroless copper processes. These results are only discussed to a limited extent, however, in order to protect the identity of the proprietary ingredients. Both chemicals have oral cancer slope factors, which were converted for dermal exposure as described in Section 3.4.3. Worker dermal exposure estimates for cyclic ether result in the following estimated upper bound excess individual lifetime cancer risks:

- For conveyorized electroless copper, 8×10^{-8} for a line operator and 9×10^{-9} for a laboratory technician.
- For non-conveyorized electroless copper, 4×10^{-7} for a line operator and 9×10^{-9} for a laboratory technician.
- For graphite, 1×10^{-7} for a line operator and 9×10^{-9} for a laboratory technician.

All of these cancer risk estimates are below the concern level of 1×10^{-6}. Worker dermal exposure estimates for alkyl oxide result in the following estimated upper bound excess individual lifetime cancer risks:[16]

- For conveyorized electroless copper, 4×10^{-9} for a line operator and 1×10^{-10} for a laboratory technician.
- For non-conveyorized electroless copper, 1×10^{-8} for a line operator and 1×10^{-10} for a laboratory technician.
- For graphite, 8×10^{-8} for a line operator and 6×10^{-9} for a laboratory technician.

Other Potential Cancer Risks. Slope factors (cancer potency values) are needed to calculate estimates of cancer risk. In addition to the chemicals discussed above,

[16] It should be noted that alkyl oxide is present in the electroless copper and graphite baths at trace concentrations (less than one part per million) and it has a relatively high tendency to evaporate. Based on air modeling estimates, and assuming 100 liter baths, all of this chemical would be released to air within one hour. The assumption that chemical concentration in the baths remains constant over time would result in this case, in large over-estimates of dermal exposure. A correction factor was applied to the calculated cancer risks to reflect exposure from the chemical being present for one hour in the baths, at a yearly frequency equal to the bath replacement frequency.

dimethylformamide and carbon black are classified as probable human carcinogens (IARC Group 2B). Like formaldehyde, the evidence for carcinogenic effects is based on animal data. However, unlike formaldehyde, slope factors are not available for either chemical. There are potential cancer risks to workers from both chemicals, but they cannot be quantified. Dimethylformamide is used in the electroless copper process. Workplace exposures have been estimated but cancer potency and cancer risk are unknown. Carbon black is used in the carbon and conductive ink processes. Occupational exposure due to air emissions from the carbon baths is expected to be negligible because the carbon process is typically conveyorized and enclosed. There may be some airborne carbon black, however, from the drying oven steps, which was not quantified in the exposure assessment. Carbon black is also used in one product line of the conductive ink process; exposures from conductive ink were not characterized. One proprietary chemical used in the electroless copper process, trisodium acetate amine B, was determined to possibly be carcinogenic to humans but does not have an established slope factor.

Non-Cancer Risk. HQs and MOEs for line operators and laboratory technicians from workplace exposures are presented in Appendix E. An HQ exceeding one indicates a potential concern. Unlike cancer risk, HQ does not express probability, only the ratio of the estimated dose to the RfD or RfC, and it is not necessarily linear (an HQ of ten does not mean that adverse health effects are ten times more likely than an HQ of one).

EPA considers high MOE values, such as values greater than 100 for a NOAEL-based MOE or 1,000 for a LOAEL-based MOE, to pose a low level of concern (Barnes and Dourson, 1988). As the MOE decreases, the level of concern increases. Chemicals are noted here to be of potential concern if a NOAEL-based MOE is lower than 100, a LOAEL-based MOE is lower than 1,000, or a MOE based on an effect level that was not specified as a LOAEL is less than 1,000. As with HQ, it is important to remember that the MOE is not a probabilistic statement of risk.

Inhalation risk indicators of concern for non-proprietary chemicals are presented in Table 3.36, and for the known proprietary chemicals in Table 3.37. This includes chemicals of potential concern based on MOE and/or HQ results, as well as cancer risk results for any chemical with a cancer slope factor. Inhalation exposure estimates are based on the assumptions that emissions to air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines.

Dermal risk indicators of concern for non-proprietary chemicals are presented in Table 3.38 and for the known proprietary chemicals in Table 3.39. This includes chemicals of potential concern based on MOE and/or HQ results, as well as cancer risk results for any chemical with a cancer slope factor. Dermal exposure estimates are based on the assumption that both hands are routinely immersed in the bath and that the worker does not wear gloves.

It should be noted that Tables 3.36 through 3.39 do not include chemicals for which toxicity data were unavailable.

Table 3.36 Summary of Human Health Risk Results From Inhalation Exposure for Selected Non-Proprietary Chemicals

Chemical of Concern[a]	Risk Indicator[a, b]			Potential Health Effects
	Electroless Copper, non-conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized	Tin-Palladium, non-conveyorized	
Copper (I) Chloride	MOE[c] (1) 420, line operator LOAEL	NA	NA	Long-term exposure to copper dust can irritate nose, mouth and eyes, and cause dizziness. Long-term exposure to high levels of copper may cause liver damage. Copper is not known to cause cancer. The seriousness of the effects of copper can be expected to increase with both level and length of exposure.
Ethanolamine	MOE (3) 68, line operator LOAEL	NA	MOE (2,3) 34, line operator LOAEL	Ethanolamine is a strong irritant. Animal studies showed that the chemical is an irritant to respiratory tract, eyes, and skin. No data were located for inhalation exposure in humans.
2-Ethoxyethanol	HQ[c] (4) 140, line operator	NA	NA	In animal studies 2-ethoxyethanol caused harmful blood effects including destruction of red blood cells and resulting in the release of hemoglobin (hemolysis) and male reproductive effects at high exposure levels. The seriousness of the effects can be expected to increase with both level and length of exposure. No data were located for inhalation exposure in humans.
Ethylene Glycol	MOE (3,5) 500, line operator Human Exposure Data	NA	NA	In humans, low levels of vapors produce throat and upper respiratory irritation. When ethylene glycol breaks down in the body, it forms chemicals that crystallize and that can collect in the body and prevent kidneys from working. The seriousness of the effects can be expected to increase with both level and length of exposure.

Chemical of Concern[a]	Risk Indicator[a, b]			Potential Health Effects
	Electroless Copper, non-conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized	Tin-Palladium, non-conveyorized	
Formaldehyde	cancer risk (1) 2×10^{-5} to 1×10^{-3}, line operator[d] MOE 0.48, line operator LOAEL	NA	NA	Formaldehyde in animals produces nasal cancer (from inhalation) at low levels. In humans, exposure at low levels in air produces skin irritation and throat and upper respiratory irritation. The seriousness of these effects can be expected to increase with both level and length of exposure.
Formic Acid	MOE 90, line operator NOAEL	NA	NA	Formic acid is a strong irritant to the skin, eyes, and mucous membranes based on clinical evidence in humans and animal toxicity data. There is also clinical evidence to indicate adverse effects on kidney function in humans, as well as central nervous system effects, such as visual and mental disturbances, following repeated exposures to high concentrations of formic acid.
Methanol	MOE (1,4,6) 370, line operator Human Exposure Data	NA	NA	Long-term exposure to methanol vapors can cause headache, irritated eyes and dizziness at high levels. No harmful effects were seen when monkeys were exposed to highly concentrated vapors of methanol. When methanol breaks down in the tissues, it forms chemicals that can collect in the tissues or blood and lead to changes in the interior of the eye causing blindness.
Sodium Hydroxide	MOE 910, line operator LOAEL	NA	NA	Sodium hydroxide is corrosive by all routes of exposure, with numerous case reports of poisonings in humans. Contact with the skin begins to cause immediate damage but not immediate pain. Acute and repeated exposures both result in damage due to the corrosive properties of the chemical. Carcinomas of the esophagus, larynx, and trachea have been reported in humans several, years after ingestion of high concentrations of sodium hydroxide.

Chemical of Concern[a]	Risk Indicator[a, b]			Potential Health Effects
	Electroless Copper, non-conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized	Tin-Palladium, non-conveyorized	
Sulfuric Acid	MOE (1,2,3,4,5,7,8) 2.8, line operator NOAEL	MOE (1,5) 24, line operator NOAEL	MOE (2,5,8) 30, line operator NOAEL	Sulfuric acid is a very strong acid and can cause structural damage to skin and eyes. Humans exposed to sulfuric acid mist at low levels in air experience a choking sensation and irritation of lower respiratory passages.

[a] This table includes results for chemicals and pathways with a MOE less than 1,000 if based on LOAELs (or less than 100 if based on NOAELs), an HQ greater than one, or a calculated cancer risk. It does not include chemicals for which toxicity data were unavailable, chemicals which have not been identified or evaluated because of their proprietary status, or chemicals used in MHC process alternatives which were not included in this evaluation.

[b] How to read this table:

A (B)
C, D
E

A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk)

B: Process bath(s) in which the chemical is used. Numbers in parenthesis indicate the process bath(s) in which the chemical is used:

(1) electroless copper bath (2) accelerator bath (3) cleaner/conditioner bath (4) anti-tarnish bath
(5) microetch bath (6) catalyst bath (7) predip bath (8) acid dip bath

C: Value calculated for risk indicator (cancer risk, HQ, or MOE).

D: Type of worker for which risk results are presented (line operator or laboratory technician).

E: Type of toxicity data used for MOE: NOAEL, LOAEL or data from human exposures which do not provide a range of exposures but identify levels which have adverse effects on humans.

[c] There is generally a higher level of confidence in the HQ than the MOE because the HQ is based on an RfD or RfC that has been peer-reviewed by EPA. MOEs are calculated for chemicals without an available RfC or RfD.

[d] To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate is provided using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 35-fold reduction in occupational formaldehyde exposure and risk.

NA: Not Applicable.

Table 3.37 Summary of Human Health Risk Results from Inhalation Exposure for Selected Proprietary Chemicals

Code Name for Chemical of Concern	Risk Indicator	Potential Health Effects
	Electroless Copper, non-conveyorized	
Alkyl Oxide	cancer risk 3×10^{-7}, line operator	Probable human carcinogen.
Alkene Diol	MOE 97, line operator LOAEL	Exposure to low levels may result in irritation of the throat and upper respiratory tract.

Note: Baths not specified to protect proprietary chemical identities.

[a] This table includes results for chemicals and pathways with a MOE less than 1,000 if based on LOAELs (or less than 100 if based on NOAELs), an HQ greater than one, or a calculated cancer risk. It does not include chemicals for which toxicity data were unavailable, chemicals which have not been identified or evaluated because of their proprietary status, or chemicals used in MHC process alternatives which were not included in this evaluation.

[b] How to read this table:

A
C, D
E

A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk)
C: Value calculated for risk indicator (cancer risk, HQ, or MOE).
D: Type of worker for which risk results are presented (line operator or laboratory technician).
E: Type of toxicity data used for MOE: NOAEL, LOAEL or data from human exposures which do not provide a range of exposures but identify levels which have adverse effects on humans.

[c] There is generally a higher level of confidence in the HQ than the MOE because the HQ is based on an RfD or RfC that has been peer-reviewed by EPA. MOEs are calculated for chemicals without an available RfC or RfD.

For inhalation exposure, 2-ethoxyethanol is the only MHC chemical with an HQ greater than one; this is for a line operator in the non-conveyorized electroless copper process. Chemicals with MOEs below the above-mentioned levels for inhalation exposure include the following:

- For non-conveyorized electroless copper: copper (I) chloride, ethanolamine, ethylene glycol, formaldehyde, formic acid, methanol, sodium hydroxide, sulfuric acid, and one proprietary chemical for a line operator.
- For non-conveyorized tin-palladium: ethanolamine and sulfuric acid for a line operator.
- For non-conveyorized non-formaldehyde electroless copper: sulfuric acid for a line operator.

Dermal risk indicators of concern for non-proprietary chemicals are presented in Table 3.38 and for the known proprietary chemicals in Table 3.39. Dermal exposure estimates are based on the assumption that workers do not wear gloves and that all non-conveyorized lines are operated by manual hoist. Chemicals with HQs from dermal exposure greater than one include:

- Formaldehyde for a line operator in the non-conveyorized electroless copper and conveyorized electroless copper processes.
- Stannous chloride for a line operator in the non-conveyorized electroless copper, non-formaldehyde electroless copper (non-conveyorized), non-conveyorized tin-palladium, and conveyorized tin-palladium processes.
- One proprietary chemical for a line operator in the conveyorized electroless copper process.

Table 3.38 Summary of Human Health Risk Results From Dermal Exposure for Selected Non-Proprietary Chemicals

Chemical of Concern[a]	Risk Indicator[a, b]					Potential Health Effects
	Electroless Copper, non-conveyorized	Electroless Copper, conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized	Tin-Palladium, non-conveyorized	Tin-Palladium, conveyorized	
Copper (I) Chloride	MOE [c] (1) 0.96, line operator 39, laboratory tech. LOAEL	MOE (1) 4.3, line operator 39, laboratory tech. LOAEL	NA	MOE (2) 1.9, line operator 190, laboratory tech. LOAEL	MOE (2) 5.2, line operator 190, laboratory tech. LOAEL	No data were located for health effects from dermal exposure in humans.
Fluoroboric Acid	MOE (2) 2.0, line operator 80, laboratory tech. Human Exposure Data	MOE (2) 8.5, line operator 80, laboratory tech. Human Exposure Data	NA	MOE (2) 4.6, line operator 460, laboratory tech. Human Exposure Data	MOE (2) 13, line operator 460, laboratory tech. Human Exposure Data	In humans, fluoroboric acid produces strong caustic effects leading to structural damage to skin and eyes.
Formaldehyde	HQ (1) 15, line operator LOAEL	HQ (1) 3.4, line operator LOAEL	NA	NA	NA	In humans, exposure at low levels in air produces skin irritation. The seriousness of these effects can be expected to increase with both level and length of exposure.
Palladium	MOE (6) 20, line operator 820, laboratory tech. LOAEL	MOE (6) 92, line operator 820, laboratory tech. LOAEL	NA	MOE (6) 5.6, line operator 560, laboratory tech. LOAEL	MOE (6) 20, line operator 560, laboratory tech. LOAEL	No specific information was located for health effects from dermal exposure in humans.
Palladium Chloride	NA	NA	NA	MOE (6) 8.9 line operator 890, laboratory tech. LOAEL	MOE (6) 32, line operator 890, laboratory tech. LOAEL	Long-term dermal exposure in humans produces contact dermatitis.
Sodium Chlorite	MOE (2) 17, line operator NOAEL	MOE (2) 73, line operator NOAEL	MOE (2) 15, line operator NOAEL	NA	NA	No specific information was located for health effects from dermal exposure to sodium chlorite in humans. Animal studies showed that the chemical produces moderate irritation of skin and eyes.

Chemical of Concern[a]	Risk Indicator[a, b]					Potential Health Effects
	Electroless Copper, non-conveyorized	Electroless Copper, conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized	Tin-Palladium, non-conveyorized	Tin-Palladium, conveyorized	
Stannous Chloride	HQ (6) 3.6, line operator	NA	HQ (6) 3.7, line operator	HQ (6) 15, line operator	HQ (6) 4.2, line operator	Mild irritation of the skin and mucous membrane has been shown from inorganic tin salts. However, no specific information was located for dermal exposure to stannous chloride in humans. Stannous chloride is only expected to be harmful at high doses; it is poorly absorbed and leaves the body rapidly.

[a] This table includes results for chemicals and pathways with a MOE less than 1,000 if based on LOAELs (or less than 100 if based on NOAELs), an HQ greater than one, or a calculated cancer risk. It does not include chemicals for which toxicity data were unavailable, chemicals which have not been identified or evaluated because of their proprietary status, or chemicals used in MHC process alternatives which were not included in this evaluation.

[b] How to read this table:

A (B)
C, D
E

A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk).

B: Process bath(s) in which the chemical is used. Numbers in parenthesis indicate the process bath(s) in which the chemical is used:

(1) electroless copper bath (2) accelerator bath (3) cleaner/conditioner bath (4) anti-tarnish bath
(5) microetch bath (6) catalyst bath (7) predip bath (8) acid dip bath

C: Value calculated for risk indicator (cancer risk, HQ, or MOE).

D: Type of worker for which risk results are presented (line operator or laboratory technician).

E: Type of toxicity data used for MOE: NOAEL; LOAEL; or data from human exposures which do not provide a range of exposures but identify levels which have adverse effects on humans.

[c] There is generally a higher level of confidence in the HQ than the MOE because the HQ is based on an RfD or RfC that has been peer-reviewed by EPA. MOEs are calculated for chemicals without an available RfC or RfD.

NA: Not Applicable.

Table 3.39 Summary of Human Health Risk Results from Dermal Exposure for Selected Proprietary Chemicals

Code Name for Chemical of Concern	Risk Indicator[a]					Potential Health Effects
	Electroless Copper, non-conveyorized	Electroless Copper, conveyorized	Graphite, conveyorized	Organic-Palladium, non-conveyorized	Organic-Palladium, conveyorized	
Nitrogen Heterocycle	MOE 130, line operator	MOE 510, line operator	NA	NA	NA	No data were located for health effects from dermal exposure in humans.
Palladium Salt	NA	NA	NA	MOE 1.5, line operator 450, lab. tech.	MOE 8.0, line operator 450, lab. tech.	Exposure may result in skin irritation and sensitivity.
Sodium Carboxylate	MOE 71, line operator	MOE 320, line operator	NA	NA	NA	No data were located for health effects from dermal exposure in humans.
Cyclic Ether	cancer risk 4×10^{-7}, line operator 9×10^{-9}, lab. tech.	cancer risk 8×10^{-8}, line operator 9×10^{-9}, lab. tech.	cancer risk 1×10^{-7}, line operator 9×10^{-9}, lab. tech.	NA	NA	Possible/probable human carcinogen.
Alkyl Oxide	cancer risk 1×10^{-8}, line operator 1×10^{-10}, lab. tech.	cancer risk 4×10^{-9}, line operator 1×10^{-10}, lab. tech.	cancer risk 8×10^{-8}, line operator 6×10^{-9}, lab. tech.	NA	NA	Long-term dermal exposure in humans produces contact dermatitis; probable human carcinogen.
Tin Salt	NA	HQ 1.1, line operator	NA	NA	NA	No data were located for health effects from dermal exposure in humans. Inorganic tin compounds may irritate the eyes, nose, throat, and skin.

[a] MOE based on LOAEL.

Note: Baths not specified to protect proprietary chemical identities.

[b] This table includes results for chemicals and pathways with a MOE less than 1,000 if based on LOAELs (or less than 100 if based on NOAELs), an HQ greater than one, or a calculated cancer risk. It does not include chemicals for which toxicity data were unavailable, chemicals which have not been identified or evaluated because of their proprietary status, or chemicals used in MHC process alternatives which were not included in this evaluation.

[c] How to read this table:

A
C, D
E

A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk).
C: Value calculated for risk indicator (cancer risk, HQ, or MOE).
D: Type of worker for which risk results are presented (line operator or laboratory technician).
E: Type of toxicity data used for MOE: NOAEL; LOAEL; or data from human exposures which do not provide a range of exposures but identify levels which have adverse effects on humans.

[d] There is generally a higher level of confidence in the HQ than the MOE because the HQ is based on an RfD or RfC that has been peer-reviewed by EPA. MOEs are calculated for chemicals without an available RfC or RfD.

NA: Not Applicable.

Chemicals with NOAEL-based MOEs lower than 100, or LOAEL-based MOEs or other MOEs lower than 1,000 for dermal exposure include the following:

- For non-conveyorized electroless copper: copper (I) chloride, fluoroboric acid, palladium, sodium chlorite, and two proprietary chemicals for a line operator; copper (I) chloride, fluoroboric acid, and palladium for a laboratory technician.
- For conveyorized electroless copper: copper (I) chloride, fluoroboric acid, palladium, sodium chlorite, and two proprietary chemicals for a line operator; copper (I) chloride, fluoroboric acid, and palladium for a laboratory technician.
- For non-conveyorized non-formaldehyde electroless copper: sodium chlorite for a line operator.
- For non-conveyorized tin-palladium: copper (I) chloride, fluoroboric acid, palladium and palladium chloride for a line operator and laboratory technician.
- For conveyorized tin-palladium: copper (I) chloride, fluoroboric acid, palladium and palladium chloride for a line operator and laboratory technician.
- For non-conveyorized organic-palladium: one proprietary chemical for a line operator and laboratory technician.
- For conveyorized organic-palladium: one proprietary chemical for a line operator and laboratory technician.

Ambient (Outdoor) Environment

Cancer Risk. As with the occupational setting, the electroless copper and graphite processes are the only processes for which a cancer risk to humans in the ambient (outdoor) environment has been estimated. Formaldehyde is the only non-proprietary chemical with cancer risks estimated for the general population. These results are for both conveyorized and non-conveyorized electroless copper processes, assuming that emissions from both process configurations are vented to the outside. The upper bound excess[17] individual lifetime cancer risk for nearby residents from the non-conveyorized electroless copper process from formaldehyde inhalation was estimated to range from 2×10^{-9} to 1×10^{-7}. The risk for nearby residents from the conveyorized electroless copper process was estimated to range from 6×10^{-9} to 3×10^{-7}. Again, the higher values (3×10^{-7} for conveyorized and 1×10^{-7} for non-conveyorized) are based on a LADDs of 7.0×10^{-6} mg/kg-day and 2.6×10^{-6} mg/kg-day, respectively, and a slope (cancer potency) factor of 0.046 per mg/kg-day. The lower values (6×10^{-9} for conveyorized and 2×10^{-9} for non-conveyorized) take into account a possible 50-fold reduction in inhalation unit risk.

The discussion of reduction in estimated cancer risk from Section 3.4.1 applies to these results as well. Formaldehyde has been classified as Group B1, a Probable Human Carcinogen based on limited evidence of carcinogenicity in humans, sufficient evidence of carcinogenicity in animals, and additional supportive evidence. These estimates indicate low concern and are

[17] *Upper bound* refers to the method of determining a slope factor, where the upper bound value (generated from a certain probability statement) for the slope of the dose-response curve is used. *Excess* means the estimated cancer risk is in addition to the already-existing background risk of an individual contracting cancer from all other causes.

interpreted to mean that, over a lifetime, an individual resident is expected to have no more than one excess chance in ten million of developing cancer from exposure to formaldehyde from a nearby facility using the non-conveyorized electroless copper process, or one excess chance in three million of developing cancer from exposure to formaldehyde from the conveyorized electroless copper process. The conveyorized electroless copper risk is slightly higher due to the larger surface areas of conveyorized baths, resulting in higher modeled air emission rates.

The graphite and electroless copper processes contain one known proprietary chemical, alkyl oxide, with an inhalation cancer slope factor. Inhalation exposure to cyclic ether, the other proprietary chemical with a cancer slope factor, is assumed negligible because the chemical is non-volatile and is not used in an air-sparged bath. The upper bound excess individual lifetime cancer risk for nearby residents from the (conveyorized) graphite process from inhalation of alkyl oxide was estimated to be 9×10^{-11}. This estimate indicates low concern and is interpreted to mean that, over a lifetime, an individual resident is expected to have no more than one excess chance in 11 billion of developing cancer from exposure to alkyl oxide from a conveyorized graphite process. The upper bound excess individual lifetime cancer risk for nearby residents from the electroless copper process from inhalation of alkyl oxide was estimated to be 1×10^{-11} for the non-conveyorized process and 3×10^{-11} for the conveyorized electroless copper process.[18] These estimates also indicate low concern and are interpreted to mean that, over a lifetime, an individual resident is expected to have no more than one excess chance of developing cancer in 100 billion for non-conveyorized electroless copper, and no more than one excess chance in 33 billion for conveyorized electroless copper from inhalation exposure to alkyl oxide.

None of the other process alternatives use chemicals for which cancer slope factors were available, so no other cancer risks were estimated. Other identified chemicals in the MHC processes are suspected carcinogens, but do not have established slope factors. Dimethylformamide and carbon black have been determined by IARC to possibly be carcinogenic to humans (IARC Group 2B). Dimethylformamide is used in the electroless copper process. Carbon black is used in the carbon and conductive ink processes. Carbon black is not expected to be released to outside air in any significant amount from a facility using the carbon process. This is because carbon black is not a volatile compound, and aerosol releases are not expected because it is not used in an air-sparged bath. Conductive ink exposures and risks were not characterized. One proprietary chemical used in the electroless copper process, trisodium acetate amine B, was determined to possibly be carcinogenic to humans but does not have an established slope factor.

Non-Cancer Risk. Appendix E presents HQs for estimated chemical releases to ambient air, and subsequent inhalation by residents near a model facility. Chemicals below the emission rate cutoff of 23 kg/year are not included because below this emission rate exposures are

[18] It should be noted that alkyl oxide is present in the electroless copper and graphite baths at trace concentrations (less than one part per million) and it has a relatively high tendency to evaporate. Based on air modeling estimates, and assuming 100 liter baths, all of this chemical would be released to air within one hour. The assumption that chemical concentration in the baths remains constant over time would result, in this case, in large over-estimates of inhalation exposure. A correction factor was applied to the calculated cancer risks to reflect exposure from the chemical being present for one hour in the baths, at a yearly frequency equal to the bath replacement frequency.

expected to be negligible. All HQs are less than one for ambient exposure to the general population, indicating low concern.

These results suggest there is low risk to nearby residents, based on incomplete but best available data. Data limitations include the use of modeled air concentrations using average data rather than site-specific, measured concentrations. For estimating ambient (outdoor) air concentrations, one key assumption is that no air pollution control technologies are used to remove airborne chemicals from facility air prior to venting it to the outside. Other data limitations are the lack of waterborne and solid waste data to characterize exposure routes in addition to inhalation, and lack of toxicity data for many chemicals.

Appendix E presents MOEs from ambient air exposures. The chemicals included are those above the emission rate cutoff and for which NOAEL or LOAEL data were available. (Also if an HQ could be calculated an MOE was not.) All MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations.

3.4.5 Uncertainties

An important component of any risk characterization is the identification and discussion of uncertainties. There are uncertainties involved in the measurement and selection of hazard data, and in the data, models and scenarios used in the Exposure Assessment. Any use of the risk characterization should include consideration of these uncertainties.

Uncertainties in the Exposure Assessment include the following:

- Accuracy of the description of exposure setting: how well the model facility used in the assessment characterizes an actual facility; the likelihood of exposure pathways actually occurring (scenario uncertainty).
- Missing data and limitations of workplace practices data: this includes possible effects of any chemicals that may not have been included (e.g., minor ingredients in the formulations, proprietary chemical identities not disclosed by suppliers); possible effects of side reactions in the baths which were not considered; and questionnaire data with limited facility responses.
- Estimating exposure levels from averaged data and modeling in the absence of measured, site-specific data.
- Data limitations in the Source Release Assessment: releases to surface water and land could not be characterized quantitatively.
- Chemical fate and transport model applicability and assumptions: how well the models and assumptions represent the situation being assessed and the extent to which the models have been validated or verified (model uncertainty).
- Parameter value uncertainty, including measurement error, sampling (or survey) error, parameter variability, and professional judgement.

Key assumptions made in the Exposure Assessment are discussed in Section 3.4.1.

Uncertainties in the hazard data (typically encountered in a hazard assessment) include the following:

- Using dose-response data from high dose studies to predict effects that may occur at low levels.
- Using data from short-term studies to predict the effects of long-term exposures.
- Using dose-response data from laboratory animals to predict effects in humans.
- Using data from homogeneous populations of laboratory animals or healthy human populations to predict the effects on the general human population, with a wide range of sensitivities. (This uncertainty is due to natural variations in human populations.)
- Using LOAELs and NOAELs in the absence of peer-reviewed RfDs and RfCs.
- Possible increased or decreased toxicity resulting from chemical interactions.
- Assuming a linear dose-response relationship for cancer risk (in this case for formaldehyde).
- Effects of chemical mixtures not included in toxicity testing (effects may be independent, additive, synergistic, or antagonistic).
- Possible effects of substances not evaluated because of a lack of chronic/subchronic toxicity data.

Another source of uncertainty comes from use of structure-activity relationships (SARs) for estimating human health hazards in the absence of experimental toxicity data. Specifically, this was done for: dimethylaminoborane, EDTA (sodium salt), fluoroboric acid, graphite, magnesium carbonate, m-nitrobenzene sulfonic acid, monopotassium peroxymonosulfate, palladium chloride, phosphoric acid, potassium bisulfate, potassium carbonate, potassium persulfate, potassium sulfate, p-toluene sulfonic acid, sodium bisulfate, sodium hypophosphite, and sodium persulfate. SARs were also used for ten proprietary chemicals.

Uncertainties in assessing risk from dermal exposure come from the use of toxicological potency factors from studies with a different route of exposure than the one under evaluation (i.e., using oral toxicity measures to estimate dermal risk). This was done for nine chemicals with oral RfDs, 15 chemicals with oral NOAELs (as noted in Tables 3.25 and 3.26), and two proprietary chemicals with oral cancer slope factors. Uncertainties in dermal risk estimates also stem from the use of default values for missing gastrointestinal absorption data. Specifically, this was done for benzotriazole, diethylene glycol ethyl ether, diethylene glycol n-butyl ether, ethanolamine, 2-ethoxyethanol, hydrogen peroxide, hydroxyacetic acid, isopropyl alcohol, potassium cyanide, sodium chlorite, and sodium cyanide.

Finally, the risk characterization does not address the potential adverse health effects associated with acute exposure to peak levels of chemicals. This type of exposure is especially important when evaluating developmental risks associated with exposure.

3.4.6 Conclusions

This risk characterization uses a health-hazard based framework and a model facility approach to compare the health risks of one MHC process technology to the risks associated which switching to an alternative technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including PWB shops in the U.S. and abroad, supplier data, and input from PWB manufacturers at project

meetings. Thus, the model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors.

When using the results of this risk characterization to compare health effects among alternatives, it is important to remember that this is a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. It should also be noted that this approach does not result in any absolute estimates or measurements of risk, and even for comparative purposes, there are several important uncertainties associated with this assessment.

Primary among these uncertainties is the incomplete identification of all chemicals among the process alternatives because of trade secret considerations. This factor alone precludes any definitive recommendations among the processes because the health risks from all relevant chemicals could not be evaluated. It should be noted here also that chemical suppliers to the PWB industry are in the sole position to fill these data gaps for a more complete assessment.[19] Without that, conclusions can only be drawn based on the best available information. It should also be noted that chemical suppliers are required to report on an MSDS (under 29 CFR Part 1910.1200) that a product contains hazardous chemicals, if present at one percent or greater of a product composition, or 0.1 percent or greater for carcinogens. The chemical manufacturer may withhold the specific chemical identity from the MSDS, provided that the MSDS discloses the properties and effects of the hazardous chemical. A review of the available MSDSs indicates that there are hazardous chemicals listed as trade secret ingredients: three in electroless copper, one in graphite, three in organic-palladium, and one in tin-palladium. Section 2.1.4 presents these results and discusses the use of MSDS information further.

Another significant source of uncertainty is the limited data available for dermal toxicity and the use of oral to dermal extrapolation when dermal toxicity data were unavailable. There is high uncertainty in using oral data for dermal exposure and in estimating dermal absorption rates, which could result in either over- or under-estimates of exposure and risk.

A third significant source of uncertainty is from the use of structure-activity relationships to estimate toxicity in the absence of measured toxicity data, and the lack of peer-reviewed toxicity data for many MHC chemicals. Other uncertainties associated with the toxicity data include the possible effects of chemical interactions on health risks, and extrapolation of animal data to estimate human health risks from exposure to formaldehyde and other PWB chemicals.

[19] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. Atotech provided information on one proprietary ingredient. W.R. Grace was preparing to transfer information on proprietary chemical ingredients in the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information on their MHC technologies. The absence of information on proprietary chemical ingredients is a significant source of uncertainty in the risk characterization. Risk information for proprietary ingredients, as available, is presented in this CTSA, but chemical identities, concentrations, and chemical properties are not listed.

Another major source of uncertainty in estimating exposure is the reliance on modeled data (i.e., modeled air concentrations) to estimate worker exposure. It should also be noted that there is no comparative evaluation of the severity of effects for which HQs and MOEs are reported.

The Exposure Assessment for this risk characterization used, whenever possible, a combination of central tendency and high-end assumptions, as would be used for an overall high-end exposure estimate. Some values used in the exposure calculations, however, are better characterized as "what-if," especially pertaining to bath concentrations, use of gloves, and process area ventilation rates for a model facility. Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a "what-if" descriptor, the entire assessment should be considered "what-if."

Among those health risks evaluated, it can be concluded that alternatives to the non-conveyorized electroless copper process appear to present a lower overall risk, due to reduced cancer risk to PWB workers when the use of formaldehyde is eliminated. Other adverse effects from chronic, low level exposures to chemicals in the alternative processes provide some basis for additional comparison. While alternatives to electroless copper appear to pose less overall risk, there is insufficient information to compare these alternatives among themselves to determine which of the alternatives pose the least risk.

Occupational Exposures and Risks

Health risk to workers are estimated for inhalation exposure to vapors and aerosols from MHC baths and for dermal exposure to MHC bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves and that all non-conveyorized lines are operated by manual hoist. Dermal exposure to line operators on non-conveyorized lines is estimated for routine line operation and maintenance (e.g., bath replacement, filter replacement, etc.), and on conveyorized lines for bath maintenance activities alone.

Risk results indicate that alternatives to the non-conveyorized electroless copper process pose lower occupational risks. However, in addition to several chemicals in the non-conveyorized electroless copper process, there are occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyorized processes as well. There are also occupational risk concerns for dermal contact with some chemicals in the electroless copper, organic-palladium, and tin-palladium processes for either conveyorized or non-conveyorized equipment.

Cancer Risk. The non-conveyorized electroless copper process contains the only non-proprietary chemical for which an occupational cancer risk has been estimated (for formaldehyde). Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The upper bound excess individual cancer risk estimate for line operators in the non-conveyorized electroless copper process from formaldehyde inhalation may be as high as

one in a thousand, but may be 50 times less, or one in 50,000.[20] Risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from three to 61 percent of the risk for a line operator.

Inhalation cancer risk was also estimated for one proprietary chemical, alkyl oxide, in the non-conveyorized electroless copper process. The line operator inhalation exposure estimate for alkyl oxide results in an estimated upper bound excess individual life time cancer risk of 3×10^{-7} (one in three million) based on high end exposure. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern.

Additionally, dermal cancer risks were estimated for two proprietary chemicals, cyclic ether and alkyl oxide, in the graphite and electroless copper processes. For the conveyorized graphite process, the dermal cancer risks for a line operator may be as high as 8×10^{-8} (about one in ten million) for the alkyl oxide and 1×10^{-7} (one in ten million) for the cyclic ether. The upper bound cancer risks for a laboratory technician were much less than the risks for a line operator. The cancer risks for a laboratory technician were 6×10^{-9} (one in 200 million) for alkyl oxide and 9×10^{-9} (one in 100 million) for cyclic ether.

For non-conveyorized electroless copper, the dermal cancer risks for the line operator may be as high as 4×10^{-7} (one in two million) for cyclic ether and 1×10^{-8} (one in 100 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risk for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

For conveyorized electroless copper, the dermal cancer risk for a line operator may be as high as 8×10^{-8} (about one in ten million) for cyclic ether and 4×10^{-9} (one in 200 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

Other identified chemicals in the MHC processes are suspected carcinogens. Dimethylformamide and carbon black have been determined by IARC to possibly be carcinogenic to humans (IARC Group 2B). Also, a proprietary trisodium acetate amine has been classified as a possible human carcinogen. Dimethylformamide and the proprietary chemical are used in the electroless copper process and carbon black is used in the carbon and conductive ink processes. There are potential cancer risks to workers from these chemicals, but because there are no slope factors, the risks cannot be quantified.

[20] To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate is provided using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 100-fold reduction in occupational formaldehyde exposure and risk.

Non-Cancer Risk. For non-cancer risk, HQs greater than one were estimated for occupational exposures to chemicals in the non-conveyorized and conveyorized electroless copper processes, the non-conveyorized and conveyorized tin-palladium processes, and the non-conveyorized non-formaldehyde electroless process. Also, several chemicals had estimated MOEs lower than 100 or LOAEL-based MOEs lower than 1,000 for occupational exposures in the non-conveyorized and conveyorized electroless copper processes, non-conveyorized and conveyorized tin-palladium processes, non-conveyorized and conveyorized organic-palladium processes, and non-conveyorized non-formaldehyde electroless copper process.

Based on calculated occupational exposure levels, there may be adverse health effects to workers exposed to these chemicals with a HQ exceeding 1.0 or an MOE less than 100 or 1,000. However, it should be emphasized that these conclusions are based on screening level estimates.

These numbers are used here for relative risk comparisons between processes, and should not be used as absolute indicators for potential health risks to MHC line workers.

Ambient (Outdoor) Exposures and Risks

Public health risk was estimated for inhalation exposure for the general populace living near a facility. Public exposure estimates are based on the assumption that emissions from both conveyorized and non-conveyorized process configurations are vented to the outside. The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern for nearby residents. The upper bound excess individual cancer risk for nearby residents from formaldehyde in the non-conveyorized electroless copper process was estimated to be from approaching zero to 1×10^{-7} (one in ten million) and from approaching zero to 3×10^{-7} (one in three million) for the conveyorized electroless copper process. Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The upper bound excess individual cancer risk for nearby residents from the proprietary alkyl oxide in the conveyorized graphite process was estimated to be from approaching zero to 9×10^{-11} (one in 11 billion); in the non-conveyorized electroless copper process from approaching zero to 1×10^{-11} (one in 100 billion), and in the conveyorized electroless copper process from approaching zero to 3×10^{-11} (one in 33 billion). All hazard quotients are less than one for ambient exposure to the general population, and all MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations for chronic non-cancer effects.

Ecological Hazards

The CTSA methodology typically evaluates ecological risk in terms of risks to aquatic organisms in streams that receive treated or untreated effluent from manufacturing processes. Stream concentrations were not available, however, and could not be estimated because of data limitations (i.e., insufficient characterization of constituents and their concentrations in facility wastewater). The upper limit of the aquatic release (and thus, its consequent exposure/risk) is controlled by regulation; the degree of control varies by site. Section 4.3, Regulatory Status, discusses the pertinent regulations. Because exposure (i.e., stream concentrations) could not be quantified, ecological (aquatic) risk is not characterized. Instead, an ecological hazard assessment was performed (Section 3.3.3), based only on chemical toxicity to aquatic organisms. The results of this evaluation are summarized briefly here.

Concern concentrations were estimated for MHC chemicals using an established EPA method. A CC is an acute or chronic toxicity value divided by an assessment factor (AsF). AsFs are dependent on the amount and type of toxicity data contained in a toxicity profile and reflect the amount of uncertainty about the potential effects associated with a toxicity value. CCs were determined for aquatic species (e.g., *Daphnia*, algae, and/or fish). The lowest CC is for copper sulfate, based on fish toxicity data.

Chemicals are also ranked for aquatic toxicity concern levels using established EPA criteria (high, moderate, and low concern) based on the available toxicity data. The number of chemicals with a high aquatic hazard concern level include nine in the electroless copper process, two in carbon, two in conductive ink, none in conductive polymer, three in graphite, three in non-formaldehyde electroless copper, two in organic-palladium, and nine in the tin-palladium process.